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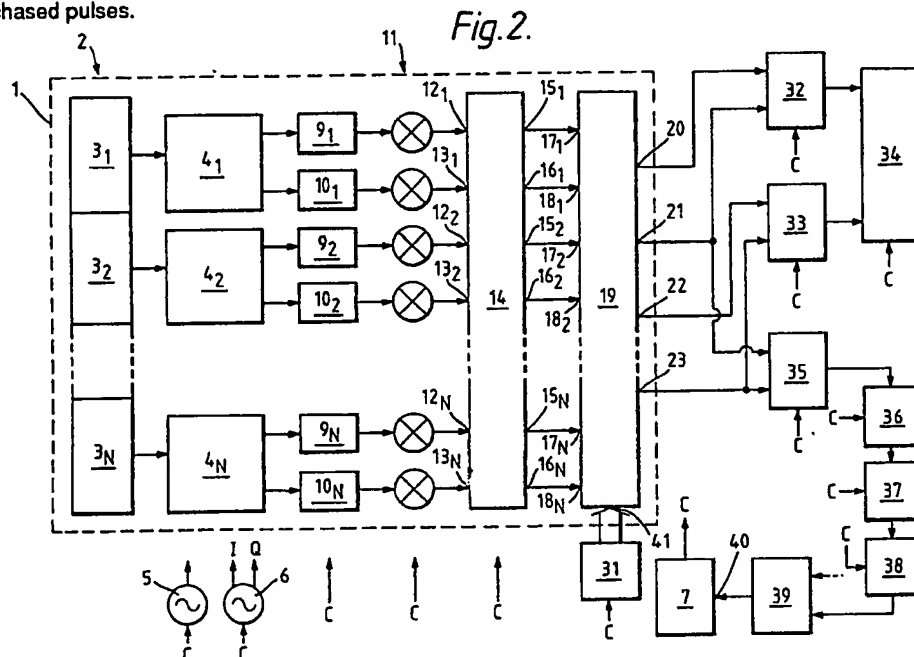
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## (54) Synchronizing a radar receiver

(57) A receiver for use in a bistatic or multistatic radar system comprises a multiple beam phased array aerial system (1) the reception beam of which is caused by means of a multiplexer (19) and a control signal generator (31) to chase respective pulses transmitted by the system transmitter. The reception beam is arranged to have two components the pointing directions of which lie side by side along the transmitted beam. These components correspond to respective outputs (20, 21 and 22, 23) of the multiplexer. The average difference between the transmitted energy received by these two components is assessed by means of a subtractor (35) and an integrator (36) and the result is used to control the output frequency of a master clock (7) which in turn controls the control signal generator (31) for the multiplexer (19). Thus the chasing is speeded up if the reception beam is lagging too far behind the chased pulses, or slowed down if the reception beam is running too far ahead of the chased pulses.

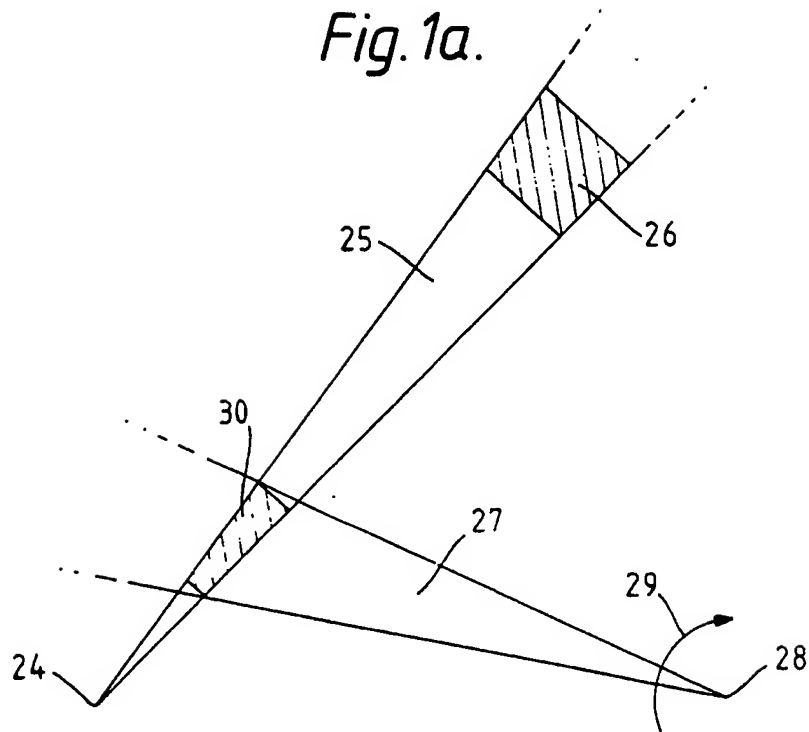


At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

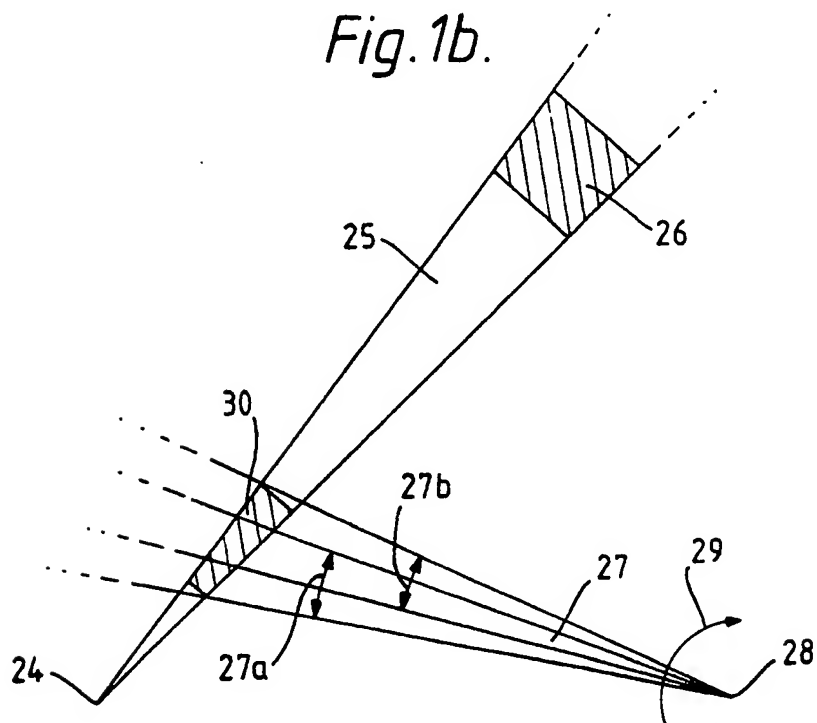
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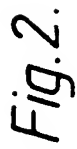
*Fig. 1a.*



*Fig. 1b.*



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## DESCRIPTION

## SYNCHRONIZING A RADAR RECEIVER

5 This invention relates to a radar receiver for a radar system which comprises a radar transmitter and a radar receiver in spaced relationship, the transmitter comprising means for transmitting a beam of pulsed radio energy and the receiver comprising an aerial system for receiving said energy after reflection by a target, said  
10 aerial system having a directional characteristic such that a reception beam is defined and the receiver including means for repeatedly scanning the reception beam along the transmitted beam so as to track reflected energy derived from respective ones of the transmitted pulses, the scanning of the reception beam being controlled by a clock included in the receiver.

15 Radar systems in which a transmitter and one or more receivers are situated in spaced-apart relationship (by a distance which is significant compared to likely target ranges) - so-called bistatic or multistatic radar systems - are well-known. An advantage of  
20 such systems in some applications is that, because the or each receiver is basically non-radiating, it is more difficult to locate than it would be if it were situated at the same site as the transmitter. However, the separation between the transmitter and the or each receiver causes several problems, one of which is that  
25 there must be highly accurate intersite synchronisation. This may be achieved, for example, by locking together a clock included in and controlling the transmitter and a clock included in and controlling the or each receiver by means of a pair of timing loops implemented across a radio link between the transmitter and the or  
30 each receiver. Such a synchronization method is discussed, for example, in a paper "Development of a Multistatic Measurement System" by J.E. Salah and J.E. Morriello in the 1980 IEEE International Radar Conference Proceedings at pages 88-93. In this known method one loop is a phase-lock loop which maintains  
35 long-term phase coherence between 10MHz clock signals at the

transmitter and receiver, and the other loop periodically (at 100 msec. intervals) sets the receiver clock time to be equal to the transmitter clock time to within 100nsec. The presence of the or each (microwave) radio link in the known system is obviously a disadvantage in those applications in which it is desired to make the receiver(s) as difficult to locate as possible, and it is an object of the present invention to enable the amount of information which needs to be communicated between transmitter and receiver(s) via such a link or equivalent to be at least reduced.

According to the invention, a radar receiver of the kind specified in the opening paragraph is characterized in that the reception beam has first and second overlapping components which have respective outputs and the pointing directions of which lie side by side along the length direction of the transmitted beam, and in that a control loop is provided for deriving from said outputs a signal indicative of the average difference between the said energy received by said first and second components respectively and feeding said signal to a frequency control input of said clock for controlling the output frequency of said clock and hence the scanning rate of the reception beam in such manner as to reduce said average difference (if any).

Pulse-type bistatic and multistatic radar systems usually employ a technique called "pulse-chasing"; see, for example, the paper "The Geometry of Bistatic Radar Systems" by M.C. Jackson in Proc. IEE, part F, Vol. 133 no. 7 (Dec. 1986). As depicted diagrammatically in Figure 1a of the accompanying drawings, the or each receiver 28 repeatedly scans (denoted by arrow 29) its reception beam 27 along the beam 25 of pulses from the transmitter 24 so as to track energy derived from respective ones of these pulses, resulting in the reception beam at all times ideally encompassing a volume of space from which echoes are potentially arriving. The instantaneous position of the reception beam 27 shown in Figure 1a is that required to receive reflected energy from a pulse shown at 26, the distance between the aerial of the

receiver 28 and the volume 30 of space at which the beams 25 and 27 intersect being equal to the distance between the volume 30 and the present position of the pulse 26. It has now been recognised that, when such a technique is employed, information about any synchronization errors present between a given receiver and the transmitter can be derived via this route, if some means can be found of sensing resulting errors occurring in the pulse-chasing. This can be done by arranging that, as illustrated diagrammatically in Figure 1b of the accompanying drawings, the reception beam 27 has first and second overlapping components 27a and 27b respectively which have respective outputs and the pointing directions of which at all times lie side by side along the length direction of the transmitted beam 25. (The overlap preferably occurs at the 3dB points of the two components). If the pulse chasing is accurate reflected energy derived from the chased pulses will lie, on average, equally within each component 27a and 27b, so that if a relatively long-term average is taken of the difference between the output signals of the two beam components due to energy derived from the chased pulses by reflection from targets and clutter, this should be zero (assuming correct balance between the two channels). A non-zero result will indicate that the reception beam 27 is running ahead of or behind reflected energy derived from the chased pulses, and hence that the scan-controlling clock in the receiver is running ahead of or behind the pulse-controlling clock in the transmitter. The sign of the result will indicate which of these situations is present and hence the result can be applied to a control input of the receiver clock to reduce the error. If such an error-correcting facility is provided in, for example, a system as described in the paper by Salah and Morriello quoted in the preamble, it may allow the periodic locking of the receiver clock to the transmitter clock to be dispensed with in favour of a single initial locking operation, or at least allow the frequency with which such locking is required to be reduced, thereby enabling the quality of information it is necessary to communicate over the intersite radio link to be reduced.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying diagrammatic drawings, in which:

Figure 1a and Figure 1b illustrate pulse-chasing, as  
5 previously referred to, and

Figure 2 is a block diagram of the embodiment.

Figure 2 is a block diagram of a radar receiver for use in a bistatic or multistatic radar system of the kind in which the radar  
10 transmitter transmits a beam of pulsed radio energy and the or each receiver includes an aerial system which has a directional characteristic such that a reception beam is defined, the reception beam being repeatedly scanned along the transmitted beam so as to track reflected energy derived from respective ones of the  
15 transmitted pulses - so-called "pulse-chasing". In order to provide the requisite reception beam scan facility the receiver of Figure 2 includes an aerial system 1 which is of the phased-array multiple beam type. System 1 comprises a linear array 2 of N, for example thirty-two, individual reception elements  $3_1-3_N$ , e.g.  
20 microwave horns. Those output signals from the reception elements 3 which are derived from the radio pulses transmitted by the radar system transmitter are amplified and translated to baseband by respective mixer/amplifier arrangements  $4_1-4_N$ . To this end each arrangement 4 may include a first mixer, fed from a common  
25 first local oscillator 5, which translates the output signal of the corresponding element 3 from e.g. the GHz frequency range to e.g. the MHz (IF) range, an IF amplifier and filter, and a second quadrature mixer, fed from a common second local oscillator 6, which translates the IF signal to baseband. The output signals of  
30 the oscillators 5 and 6 are each phase-locked to the output signal of a high-stability master clock 7, e.g. an atomic clock of the rubidium type. The output frequency of the clock 7 may be, for example 10MHz. The two quadrature output signals I and Q of each mixer/amplifier arrangement 4 are converted to digital form by  
35 means of individual analogue-to-digital converters  $9_1-9_N$  and

10<sub>1</sub>-10<sub>N</sub> respectively, and the results are multiplied by  
respective calibration factors in respective digital multipliers 11  
to compensate for phase and amplitude mismatches which may occur  
between the various elements 3. After multiplication by the  
respective calibration factors the digital I and Q signals derived  
5 from each element 3 are applied to a corresponding pair of complex  
amplitude inputs 12<sub>1</sub>-12<sub>N</sub> and 13<sub>1</sub>-13<sub>N</sub> respectively of an  
N-(complex) point Discrete Fourier Transform calculating  
arrangement 14.

10 The arrangement 14 has, in normal manner, N pairs of  
corresponding complex amplitude outputs 15<sub>1</sub>-15<sub>N</sub> and 16<sub>1</sub>-16<sub>N</sub>  
respectively on which appear, for a given orientation of the array  
2, simultaneous signals corresponding to respective reception beams  
which point in respective directions to together form a fan-shaped  
beam. Thus, for example, a given area may be scanned in azimuth by  
15 fixedly positioning the array 2 horizontally and then simply  
switching the various output pairs 15<sub>1</sub>,16<sub>1</sub> - 15<sub>N</sub>,16<sub>N</sub> to an  
output in succession. As another example, a single stationary  
reception beam covering a wider angle than that covered by each of  
the N elementary reception beams by itself may be created by simply  
20 adding together the output signals corresponding to two or more  
adjacent elementary reception beams. As yet another example the  
above two measures may be combined, the area effectively being  
scanned by a wider-angle beam the angle of which may even be varied  
during the scan if desired.

25 The output pairs 15,16 of the DFT-calculating arrangement 14  
are connected to corresponding input pairs 17<sub>1</sub>-17<sub>N</sub>, 18<sub>1</sub>-18<sub>N</sub>  
of a switching unit 19 whose function is to implement scanning  
operations similar to those illustrated in Figure 1b.

30 It will be assumed for simplicity and ease of description that  
the outputs of the two beam components 27a and 27b of Figure 1b  
correspond, at all scan positions of the composite beam, simply to  
adjacent output pairs 15,16 of the DFT-calculating arrangement 14  
of Figure 2, although in practice it may be found beneficial to  
35 build up each component 27a and 27b itself from a plurality of



adjacent elementary beams (a "cluster") at least for some scan positions. The switching unit 19 accordingly takes the form of a four-out-of-sixty-four digital multiplexer the four outputs of which are numbered 20,21,22 and 23 respectively in Figure 2.

5        Multiplexer 19 is controlled by means of a control signal generator 31 to simultaneously couple its inputs  
15<sub>1</sub>,16<sub>1</sub>,15<sub>2</sub>,15<sub>2</sub> to its outputs 20,21,22 and 23  
respectively, then to simultaneously couple its inputs  
15<sub>2</sub>,16<sub>2</sub>,15<sub>3</sub>,16<sub>3</sub> to its outputs 20,21,22 and 23  
10        respectively, and so on until it couples its inputs  
15<sub>N-1</sub>,16<sub>N-1</sub>,15<sub>N</sub>,16<sub>N</sub> to its outputs 20,21,22 and 23  
respectively, after which the cycle repeats. Thus, during each  
cycle, the complex amplitudes appearing at the outputs 20,21  
correspond in succession to elementary reception beams 1 to N-1  
15        while, simultaneously, the complex amplitudes appearing at the  
outputs 22,23 correspond in succession to elementary reception  
beams 2 to N. Thus at every stage of a cycle the complex amplitude  
at outputs 20 and 21 corresponds to a particular one of the beam  
components 27a and 27b, say component 27a, of Figure 1b, whereas  
20        the complex amplitude at outputs 22 and 23 corresponds to the other  
beam component, i.e. component 27b in the present example, the two  
components being effectively swept together in azimuth during the  
course of the cycle. The use of the DFT-calculating arrangement 14  
to form the respective beams ensures that adjacent elementary  
25        reception beams, and hence the two reception beam components,  
overlap at their 3dB points, which is the preferred degree of  
overlap as mentioned previously.

      The two beam components 27a and 27b are combined into a single  
(swept) reception beam 27 for further processing in the receiver by  
30        adding the successive amplitudes appearing at the output 20 of  
multiplexer 19 to the corresponding successive amplitudes appearing  
at the output 22, and adding the successive amplitudes appearing at  
the output 21 to the corresponding successive amplitudes appearing  
at the output 23. These additions are performed in digital adders  
35        32 and 33 respectively, which in consequence produce I and Q

components respectively of the successive amplitudes received by the single composite beam 27. Further processing of these amplitudes, which may be conventional, is denoted by a block 34.

Furthermore the difference between the respective signals received by the two beam components 27a and 27b, or at least the difference between specific quadrature components of each, is continuously assessed. In the embodiment of Figure 2 it is the successive differences which occur between the Q components of the respective signals (these Q components appearing at the outputs 21 and 23 respectively of multiplexer 19), which are assessed by means of a digital subtractor 35. The long-term average of these differences is taken by means of an integrator 36, which may have a time constant of the order of  $10^6$  times the duration of each pulse transmitted by the system transmitter, and the result is converted to analogue form by means of a digital-to-analogue converter 37. The output of converter 37 is low-pass filtered in a filter 38 and, after the output signal(s) of any other frequency control loop with which the receiver may be provided has/have been added to it in an adder 39, is applied to a frequency control input 40 of the master clock 7.

Master clock 7 controls, inter alia, the clocking of the control signal generator 31, and hence controls the rate at which the beam 27 of Figure 1b scans along the transmitter beam 25. The output of filter 38 in Figure 2 is applied to the frequency control input 40 of clock 7 in such a sense that, if the signals appearing at the output 21 of multiplexer 19 (which signals correspond to beam 27a in Figure 1b) are less in the long term than the signals appearing at output 23 (which signals correspond to beam 27b), the frequency of clock 7 is increased, thereby advancing the scan, whereas if the signals appearing at the output 21 are in the long term greater than the signals appearing at the output 23 the frequency of clock 7 is reduced, thereby retarding the scan.

As mentioned previously, the output signals of the local oscillators 5 and 6 are phase-locked to the output signal of the master clock 7, which also controls the clocking of the control

signal generator 31. Clock 7 also controls the clocking of the A/D converters 9 and 10, the multipliers 11, the DFT calculating arrangement 19, the adders 32 and 33, the processing in the block 34, the subtractor 35, the integrator 36 and the D/A converter 37. In order not to over-complicate the drawing this clocking and phase control is indicated merely by arrows C. In a particular embodiment the clock rate was 5MHz, obtained from the output signal of (10MHz) master clock 7 by means of a frequency divider-by-two (not shown).

The control signal generator 31 may comprise a read-only memory provided with a resettable address counter clocked via the clock input C, the output of the memory being coupled to the control input 41 of the multiplexer 19. In such a case the memory will be programmed so that, starting from reset of the address counter, it subsequently outputs in succession control signals for the multiplexer 19 such that the receiver reception beam chases pulses transmitted by the system transmitter in the manner described with reference to Figure 1b. Obviously for this result to occur the reset instant of the address counter will have to coincide with a predetermined point in the (predetermined) pulse generation cycle of the transmitter (and also with a predetermined point in the (predetermined) scan cycle of the transmitted beam if the transmitted beam is itself made to scan). This may be caused to be so by arranging that the pulse generation at the transmitter, and the scanning by the transmitted beam if present, is under the control of a similarly clocked counter situated at the transmitter, the clocked transmitter and receiver counters being initially reset simultaneously, for example by temporarily bringing them together, or remotely e.g in the manner described in the aforementioned paper by Salah and Morriello. Subsequently the receiver clock 7 is controlled to run at the same rate as the corresponding clock at the transmitter by means of the control loop including the components 35-39 of Figure 2, possibly in conjunction with one or more other control loops, e.g. a phase control loop similar to that described in the paper by Salah and Morriello.

It will be appreciated that, if the transmitted beam is itself caused to scan, the orientation of the array 2 of reception elements 3 in Figure 2 will have to be varied accordingly, so that the composite fan-shaped reception beam produced by the elements  $3_1-3_N$  and the transmitted beam always lie in the same plane. This can be achieved by making the orientation of the array 2 mechanically adjustable in such manner that it depends in an appropriate way on the instantaneous output of the address counter included in the control signal generator 31. In such a case the output of the address counter may be coupled to a control signal input of a suitable mechanical orientation-adjusting arrangement via an appropriately programmed decoder. Alternatively the one-dimensional array 2 of elements 3 may be augmented by further one-dimensional arrays and corresponding components 4,9,10,11 and 14 so that a two-dimensional array is formed, the reception beam of such an arrangement being scannable in two orthogonal directions, and hence in directions in between, by appropriately upgrading the multiplexer 19.

The "subtractor" 35 of Figure 2 may in fact be constituted by a simple (digital) comparator, and the integrator 36 by a simple up-down clocked counter the up-down control input of which is fed from the output of the comparator. If this is the case it should of course be ensured that (a) the digital-to-analogue converter 37 produces zero output when the contents of the counter corresponds to approximately half the total counter capacity and (b) the counter stops rather than overflows or underflows when it reaches its maximum or minimum count respectively.

Although the control loop including the components 35-39 of Figure 2 is, as described, continuously active, it will be appreciated that this is not necessarily the case. The integration process in the integrator 36 may, for example, be temporarily stopped during intervals between the chasing of one transmitted pulse by the reception beam and the chasing of another, if such intervals occur.

Although the receiver aerial system 1 described is of the

multiple-beam phased-array type, it will be appreciated that this is not essential. For example, the system 1 could, as an alternative, be constituted by two independent beam-forming arrangements the beams formed by which are steered together.

5 From reading the present disclosure, other modifications will be apparent to persons skilled in the art. Such modifications may involve other features which are already known in the design, manufacture and use of radar receivers and component parts thereof and which may be used instead of or in addition to features already  
10 described herein. Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of the disclosure of the present application also includes any novel feature or any novel combination of features disclosed herein either explicitly or  
15 implicitly or any generalisation thereof, whether or not it relates to the same invention as presently claimed in any claim and whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to such features and/or combinations  
20 of such features during the prosecution of the present application or of any further application derived therefrom.

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## CLAIM(S)

1. A radar receiver for a radar system which comprises a radar transmitter and a radar receiver in spaced relationship, the transmitter comprising means for transmitting a beam of pulsed radio energy and the receiver comprising an aerial system for receiving said energy after reflection by a target, said aerial system having a directional characteristic such that a reception beam is defined and the receiver including means for repeatedly scanning the reception beam along the transmitted beam so as to track reflected energy derived from respective ones of the transmitted pulses, the scanning of the reception beam being controlled by a clock included in the receiver, characterized in that the reception beam has first and second overlapping components which have respective outputs and the pointing directions of which lie side by side along the length direction of the transmitted beam, and in that a control loop is provided for deriving from said outputs a signal indicative of the average difference between the said energy received by said first and second components respectively and feeding said signal to a frequency control input of said clock for controlling the output frequency of said clock and hence the scanning rate of the reception beam in such manner as to reduce said average difference (if any).

2. A receiver as claimed in Claim 1, wherein said control loop includes a comparator having inputs coupled to the outputs of said first and second reception beam components respectively, and a clocked up-down counter an up-down control input of which is coupled to the output of the comparator.

3. A receiver as claimed in Claim 1 or Claim 2, including means for deriving a signal representative of the sum of said energy received by said first and second reception beam components from the outputs of said components.

4. A receiver as claimed in Claim 3, wherein said first and second reception beam components overlap at their 3dB points.

5. A radar receiver substantially as described herein with reference to Figure 2 of the drawings.

Patents Act 1977  
Examiner's report to the Comptroller under  
Section 17 (The Search Report)

12

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Relevant Technical fields

(i) UK Cl (Edition K ) HYD (DRPZ)

(ii) Int Cl (Edition 5 ) G01S

Search Examiner

MR KING

Databases (see over)

(i) UK Patent Office

(ii)

Online database : INSPEC WPI

Date of Search

12 MARCH 1991

Documents considered relevant following a search in respect of claims

1-5

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	1

SF2(p)

54SAAX

Category	Identity of document and relevant passages - 13 -	Relevant to claim(s)

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